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Removal of Terrain Effects from SAR Satellite Imagery of Artic Tundra, Goering, Chen, Hinzman cont. & Kane, IEE Trans on Geoscience and Remote Sensing, Vol 33, No 1, Jan 1995

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(54) **Compensating for backscattered light**

(57) An image of a scene partially obscured by backscattered light is enhanced by taking account of variations in the mean backscattered flux component resulting from variations in the distance between the point from which the image is captured and points in the terrain contributing to the scene. A series of images of the scene is captured, and an averaged image is produced in which each pixel has a brightness which is an average of the brightness of those portions of the captured images that represent the same region of the scene as that pixel. A model is defined to represent the relationship between the brightness of a pixel of the averaged image and the distance between the point the view from which the image represents and the point in the scene represented by that pixel of the image. An estimate of the contribution of backscattered light to the brightness of each pixel of the image is computed from the model. The estimated contribution for each pixel is then subtracted from the brightness of that pixel of the image to produce a modified brightness for that element. The image is reconstructed with each element of the reconstructed image having a brightness which is a function of the modified brightness of that element.

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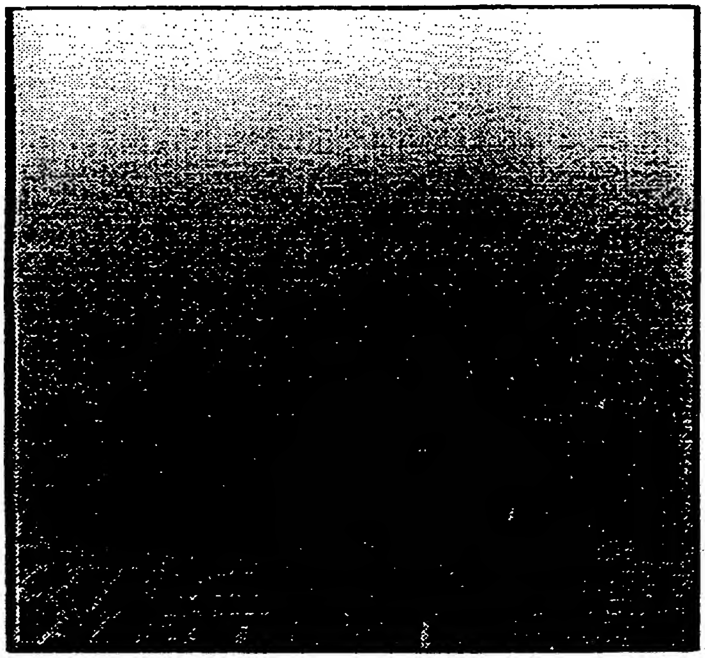

FIG.1

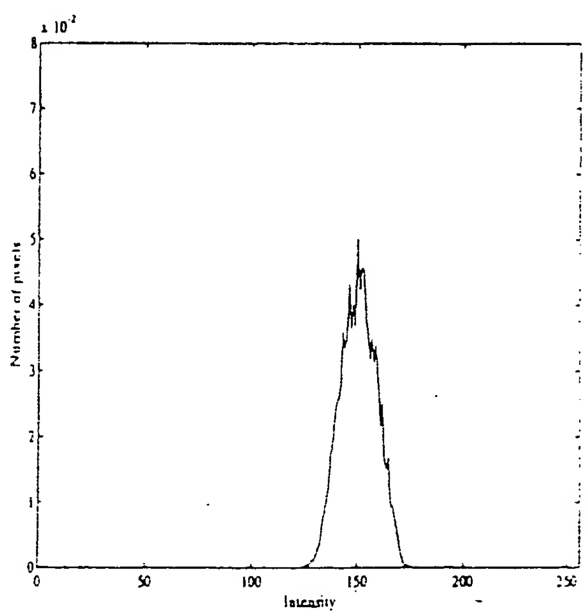

FIG.2

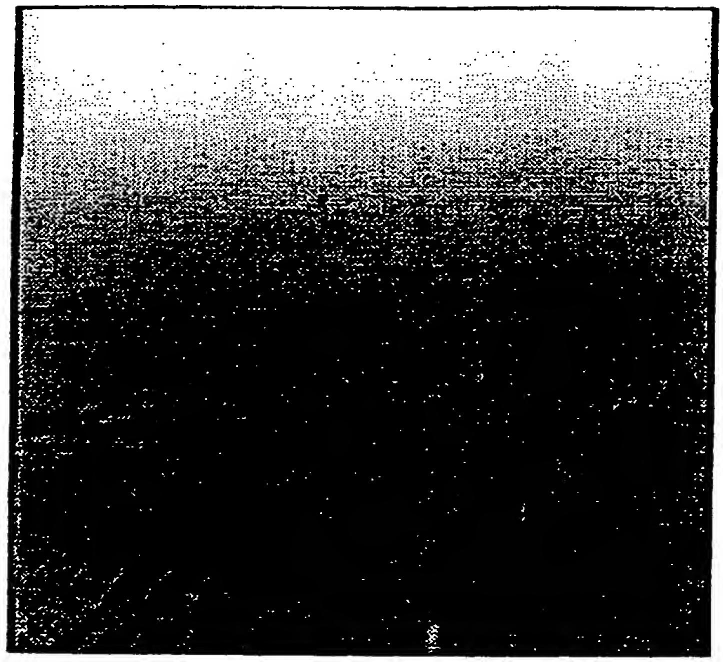

FIG. 3

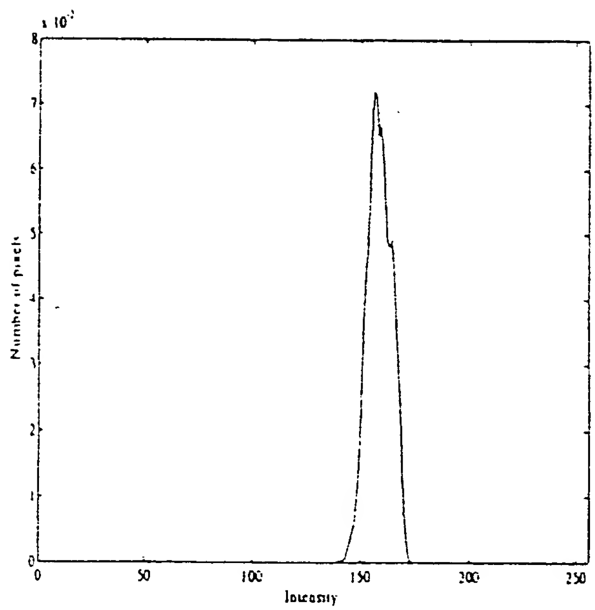

FIG. 4

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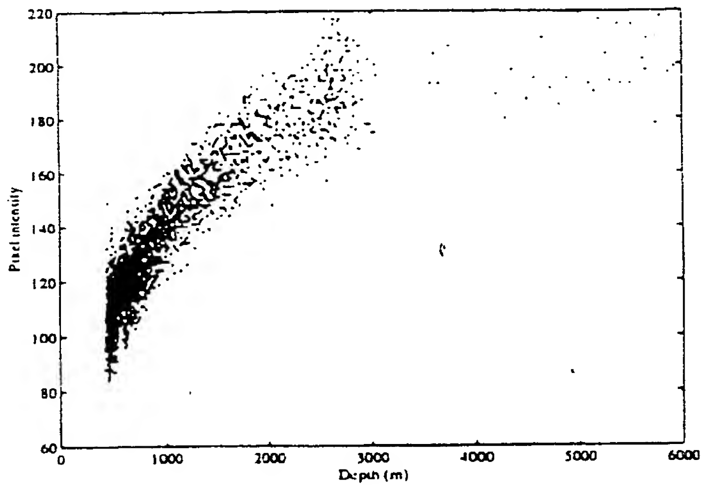

FIG. 5

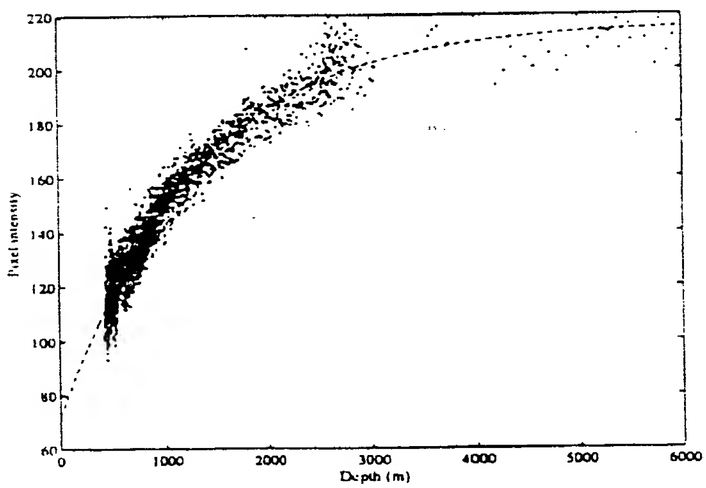

FIG. 6

FIG. 7

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IMAGE ENHANCEMENT

The present invention relates to image enhancement, and in particular to a method and apparatus for enhancing an image of a scene partially obscured by backscattered light.

Various techniques are known for enhancing images of scenes which are obscured by light backscattered from, for example, the atmosphere. For example, a camera may be mounted on an aircraft to obtain a view of the terrain scene over which that aircraft is flying. Assuming that the scene is obscured by low mist, cloud or other atmospheric effects, the intensity of light reaching the camera from those terrain features contributing to the scene is reduced. A small amount of light scattered from the terrain does reach the camera, but this is obscured by light scattered from the mist or cloud. There are many known methods for enhancing the contrast of images in such circumstances, but the maximum improvement in the quality of the image is limited by three factors.

Firstly, the gain of the camera or other sensing system is set, usually by an automatic gain control, to the maximum brightness of the image. When the scattered light component is large, the transmitted terrain component becomes small in comparison with the quantisation noise of the sensor.

Secondly, the back scattered light has a random nature, and this is a source of noise which is amplified by any contrast-stretching transformation implemented by the sensor.

Thirdly, in low light conditions, statistical fluctuations in the transmitted photon flux give rise to Poisson noise in the image. This noise will be amplified by any transformation that increases the range of contrasts present in the image.

It is known to generate an enhanced image of a scene by averaging information related to the scene captured in the form of a series of images representing its appearance from a series of different positions. This technique relies upon prior knowledge of the scene in that the enhanced image is generated by allocating to each pixel of the enhanced image a brightness which is the average of the brightness of those portions of the series of images that represent the same part of the scene as that pixel of the enhanced image. This requires knowledge of the position, relative to the scene, from which each of the series of images was captured and details of the terrain, so that compensation can be made for motion of the aircraft as the series of images is generated. Given knowledge of the position from which each image of that terrain was captured, and the field of view represented by each of the

series of images, the images can, in effect, be overlaid in appropriate positions so as to enable computation of the average brightness values. A Digital Terrain Elevation (DTE) database is already available, together with accurate information about instantaneous aircraft velocity and attitude, from on board navigation systems in many modern aircraft. The known motion-compensated image averaging systems do provide a significant improvement in image quality in conditions of high sensor noise.

Enhanced images generated using the known motion-compensated averaging systems may be further improved by contrast enhancement. Various contrast enhancement algorithms are known, for example variance normalisation or histogram equalisation. In practice however such known contrast enhancement algorithms have not provided particularly good results.

It is an object of the present invention to provide an improved method and apparatus for enhancing an image of a scene partially obscured by backscattered light.

According to the present invention, there is provided a method for producing an enhanced image of a scene partially obscured by backscattered light, wherein a series of images of the scene is captured, an averaged image is produced in which each pixel has a brightness which is an average of the brightness of those portions of the captured images that represent the same region of the scene as that pixel, a model is defined to represent the relationship between the brightness of a pixel of the averaged image and the distance between the point the view from which the image represents and the point in the scene represented by that pixel, an estimate of the contribution of backscattered light to the brightness of each pixel of the image is computed from the model, the estimated contribution for each pixel is subtracted from the brightness of that pixel to produce a modified brightness for that pixel, and the enhanced image is formed by allocating to each pixel of the image a brightness which is a function of the modified brightness of that pixel.

The invention also provides an apparatus for producing an enhanced image of a scene partially obscured by backscattered light, comprising means for capturing a series of images of the scene, means for producing an averaged image in which each pixel has a brightness which is an average of the brightness of those portions of the captured images that represent the same region of the scene as that pixel, means for defining a model to represent the relationship between the brightness of a pixel of the averaged image and the distance between the point the view from which the image represents and the point in the scene represented by

that pixel of the image, means for computing an estimate of the contribution of backscattered light to the brightness of each pixel of the image from the model, means for subtracting the estimated contribution for each pixel from the brightness of that pixel of the image to produce a modified brightness for that pixel, and means for reconstructing the image with each pixel of the reconstructed image having a brightness which is a function of the modified brightness of that pixel.

The present invention is based on the realisation that the mean backscattered flux component in an image of a scene obscured for example by cloud will vary according to the distance between the point from which the image was captured and the points in the terrain represented in the image. Depending on the type of view, this distance (or depth) will vary across the image. This is particularly the case with aircraft flying generally horizontally across the surface of the earth. The invention considers these image-plane variations of depth and as a result is robust to variations in mean backscatter.

The model may be defined by reference to a plot of the depth/brightness relationship for the individual image to be enhanced.

The brightness of each pixel of the enhanced image may be computed from the modified brightness of that pixel scaled to restore the image contrast, for example by computing the contribution of light from the scene to the brightness of each pixel of the image on the basis of the model, dividing the modified brightness for each pixel by the estimated contribution from the scene for that element, and multiplying the resultant by the a constant to determine the brightness of the pixel in the enhanced image.

An embodiment of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a single unprocessed optical image captured by an airborne camera;

Figure 2 is a histogram of the image of Figure 1 plotting the intensity against the number of pixels in the image having particular intensities;

Figure 3 is an image of the same scene as that represented in Figure 1 but representing the image resulting from the motion-compensated average of ten frames captured sequentially;

Figure 4 is a histogram corresponding to that of Figure 2 but relating to the image of Figure 3;

Figure 5 plots the depth to brightness relationship of the pixels of the image of Figure 1;

Figure 6 plots the depth to brightness relationship of the pixels of Figure 3; and

Figure 7 is an image derived from the image of Figure 3 in accordance with the present invention.

The method of image enhancement described below has three steps, that is image averaging, parameter estimation, and contrast transformation. Image averaging techniques used are conventional, the present invention residing in the combination of these conventional techniques with the parameter estimation and contrast transformation steps.

The images described below were obtained from a standard video camera with a field of view of 30^0. The camera was mounted on an aircraft of an angle at approximate by 15^0 to the horizontal. Information about the current position, velocity and orientation of the aircraft was made available form an on board Inertial Navigation System (INS). A database of terrain height values was stored in the onboard computer. Figure 1 represent a single unprocessed image generated by the camera. The image is of a scene including a major road, vehicles travelling on that road, bridges across the road, and various terrain features to both sides of the road. The features of the scene are obscured by low level cloud. A series of ten images was taken by the camera as the aircraft travelled relative to the imaged scene. Motion-compensated averaging was then applied, the averaging being computed over the ten image frames. The image averaging is performed such that the "averaged" image at frame N is derived from the sum of a number of previous frames, using a geometric transformation to correct for the camera movements. As a result a time-averaged image is maintained which always reflects the current camera position and orientation. Each pixel in this averaged image corresponds to some particular point of the terrain which contributes to the image. Assuming worldspace (terrain) co-ordinates (x, y, z) this can be written as the sum:

$$p = \frac{1}{M}\sum_{k=0}^{M-1} I_k(x_k, y_k). \qquad (1)$$

where M is the number of images involved in the averaging process, I_k is the input image frame k. (x_k, y_k) is the position of the point (x, y, z) in frame k.

The averaging process described by equation (1) has two effects:

1. The sensor noise is reduced by a factor of approximately $\frac{1}{\sqrt{M}}$

2. The statistical fluctuations in the backscattered component are also reduced by a similar factor.

Figure 2 is a histogram based on the image of Figure 1 and representing the number of pixels in that image having the identified intensities. This histogram is dominated by the backscattered light from the cloud. Figure 3 shows the image which results from the motion-compensated average of ten frames, and Figure 4 is a histogram corresponding to that of Figure 2 but in respect of the image of Figure 3. Figure 4 shows a narrower distribution of values around the mean gray level than Figure 2. The light flux which has been reflected from the terrain is contained within this relatively narrow peak and can now be recovered by contrast enhancement. Various contrast enhancement algorithms such as variance normalisation or histogram equalisation are suitable for this purpose. One simple algorithm which could be used applies the transformation $y = mx + c$ to the image gray levels, with the constant m chosen to give good image contrast. In practice however the mean backscattered flux component will vary according to the distance between the camera and the terrain. Depending on the type of view, this distance (or depth) will vary across the image. As a result the known contrast enhancement algorithms do not result in a very significant improvement in the quality of the image represented in Figure 3. The present invention however considers these image-plane variations of depth and as a result is robust to variations in mean backscatter.

In accordance with the invention, the backscatter contribution is estimated in each pixel in the image. This is achieved by considering the depth to brightness relationship of many of the pixels in the averaged image. A parametric model is then fitted to the depth/brightness data using a numerical data-fitting algorithm. The resulting model parameters are then used to calculate backscatter at any image pixel. This method of backscatter estimation also provides parameters for contrast enhancement.

Figure 5 plots the depth to brightness relationship of the pixels of the image of Figure 1. Figure 6 plots the same data for Figure 3. As might be expected, the motion-compensated average image of Figure 3 shows less scatter and therefore represents a better starting point for the application of the present invention.

The steps of parameter estimation and contrast transformation in one implementation of the present invention will now be described.

An estimate for the backscatter contribution, $b = b(d)$, at each pixel of the image of Figure 3 may be obtained from the equation:

$$b(d) = \frac{I}{K}\left(1 - \exp(-Kd)\right), \tag{2}$$

where I is a constant which depends on the illumination, K is the extinction coefficient which characterises the scattering profile of the fog/mist/cloud particles, and d is the depth at each pixel. Similarly, an estimate for the transmitted terrain contribution at each pixel is given by

$$t(d) = T\exp\left(-Kd\right) \tag{3}$$

where T is a constant depending on I and the nature of the terrain scene. According to the depth-based model, the overall brightness $p(d)$ at a pixel with a depth d is the sum of the backscatter $b(d)$ and the light reflected from the terrain $t(d)$, that is

$$\begin{aligned} p(d) &= b(d) + t(d) \\ &= \frac{I}{K}\left(1 - \exp(-Kd)\right) + T\exp(-Kd) \end{aligned} \tag{4}$$

In order to estimate the parameters T, I and K, a three parameter model was fitted to the brightness/depth plot of Figure 6. This model is defined by the equation

$$p(d) = c_0 + c_1\exp(-Kd), \tag{5}$$

where $c_0 = \frac{I}{K}$, and $c_1 = T - \frac{I}{K}$

The model fit is carried out by using a numerical optimisation algorithm to determine values for c_0, c_0, and K such that the total least squares difference, defined by

$$\sum_{all\ i,j}\left[p(i,j) - (c_0 + c_1\exp(Kd(i,j)))\right]^2 \tag{6}$$

where $p(i,j)$ is the brightness of the averaged image at pixel (i,j) and $d(i,j)$ is the corresponding depth, is minimised. The dotted line in Figure 6 shows the parametric model. The estimated values for c_0, c_0 and were 217.55, - 145.65 and 0.773 respectively.

The backscatter estimate $b(i,j)$ at pixel (i,j) is then given by

$$b(i,j) = c_0(1 - \exp(-Kd(i,J))) \tag{7}$$

and the terrain contribution $t(i,j)$ is given by

$$t(i,j) = (c_0 + c_1)\exp(-Kd(i,j)) \tag{8}$$

Note that the estimate for $t(i,j)$ takes account of the attenuation of the terrain-reflected light by the scattering medium.

The enhanced image $e(i,j)$ at pixel (i,j) is then generated from the formula

$$e(i,j) = (p(i,j) - b(i,j))\frac{128}{t(i,j)} \qquad (9)$$

where $b(i,j)$ and $t(i,j)$ are calculated using equations (7) and (8) respectively. This is equivalent to subtracting the backscatter and scaling to restore full contrast. Note that the images are quantified to 256 gray levels. The final result is shown in Figure 7.

A check may be incorporated to ensure that the image data conforms to the model. Images in which the extinction coefficient is non-uniform tend to cause failure (the production of large or negative pixel values) for large depth values. The algorithm may detect any pixels at which the model is violated, and set the gray level of these pixels to the maximum value of 255 (i.e white).

It will be appreciated that alternative methods for estimating the backscattered contribution could be used. For example the backscattered contribution could be estimated by applying a low-pass filter to the averaged image. However, this estimate would be degraded by any low spatial frequency components in the terrain signals. Also the size of the filter kernel would have to be small with respect to the expected variation in depth. This would mean that the backscatter estimates from the filter would be subject to a greater degree of random uncertainty that with the estimation method described above.

It will also be appreciated that alternative algorithms could be applied to contrast transformation. that is the final generation of the enhanced image from the estimated backscatter and transmitted terrain contributions.

CLAIMS

1. A method for producing an enhanced image of a scene partially obscured by backscattered light, wherein a series of images of the scene is captured, an averaged image is produced in which each pixel has a brightness which is an average of the brightness of those portions of the captured images that represent the same region of the scene as that pixel, a model is defined to represent the relationship between the brightness of a pixel of the averaged image and the distance between the point the view from which the image represents and the point in the scene represented by that pixel, an estimate of the contribution of backscattered light to the brightness of each pixel of the image is computed from the model, the estimated contribution for each pixel is subtracted from the brightness of that pixel to produce a modified brightness for that pixel, and the enhanced image is formed by allocating to each pixel of the image a brightness which is a function of the modified brightness of that pixel.

2. A method according to claim 1, wherein each element of the enhanced image has a brightness computed from the modified brightness of that pixel scaled to restore image contrast.

3. A method according to claim 2, wherein an estimate of the contribution of light from the scene to the brightness of each pixel of the image is computed from the model, and the modified brightness for each pixel is divided by the estimated contribution from the scene for that pixel and multiplied by a constant to determine the element brightness in the reconstructed image.

4. A method according to any preceding claim, wherein the series of images is made up from motion-improved images of the scene captured from different positions relative to the scene.

5. An apparatus for producing an enhanced image of a scene partially obscured by backscattered light, comprising means for capturing a series of images of the scene, means for

producing an averaged image in which each pixel has a brightness which is an average of the brightness of those portions of the captured images that represent the same region of the scene as that pixel, means for defining a model to represent the relationship between the brightness of a pixel of the averaged image and the distance between the point the view from which the image represents and the point in the scene represented by that pixel of the image, means for computing an estimate of the contribution of backscattered light to the brightness of each pixel of the image from the model, means for subtracting the estimated contribution for each pixel from the brightness of that pixel of the image to produce a modified brightness for that pixel, and means for reconstructing the image with each pixel of the reconstructed image having a brightness which is a function of the modified brightness of that pixel.

6. A method for producing an enhanced image of a scene partially obscured by backscattered light substantially as hereinbefore described with reference to the accompanying drawings.

7. An apparatus for enhancing an image of a scene partially obscured by backscattered light substantially as hereinbefore described with reference to the accompanying drawings.

10

Patents Act 1977 **Examiner's report to the Comptroller under Section 17** **(The Search report)**	Application number GB 9515937.2
Relevant Technical Fields (i) UK Cl (Ed.N) B7L (LT). B8B (BDC). B8H (HGCX, HGHA, HGHB, HGHX, HGMC, HGMX) (ii) Int Cl (Ed.6) A61G 7/10, 7/12, 7/14. B66D 3/00, 3/02, 3/18	Search Examiner D McMUNN Date of completion of Search 18 OCTOBER 1995
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE: WPI	Documents considered relevant following a search in respect of Claims :- 1-10

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E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
A	EP 0361397 A2	(UNIVERSITY OF NEW YORK) see Figure 2	1
A	US 5337908	(BECK) see Figures 3 and 4	1

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